

CLASSIFICATION **CONFIDENTIAL**
CENTRAL INTELLIGENCE AGENCYINFORMATION FROM
FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT

50X1-HUM

CD NO.

COUNTRY USSR

DATE OF
INFORMATION 1941 - 43

SUBJECT Scientific - Detonation phenomena

HOW
PUBLISHED Book

DATE DIST. 27 Jul 1949

WHERE
PUBLISHED Moscow

NO. OF PAGES 7

DATE
PUBLISHED 1945SUPPLEMENT TO
REPORT NO.

LANGUAGE Russian

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE
OF THE UNITED STATES WITHIN THE MEANINGS OF ESPIONAGE ACT 50
U. S. C. 31 AND 32, AS AMENDED. ITS TRANSMISSION OR THE REVELATION
OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PRO-
HIBITED BY LAW. REPRODUCTION OF THIS FORM IS PROHIBITED.

THIS IS UNEVALUATED INFORMATION

SOURCE

Nauchno-Issledovatel'skiye Raboty Khimicheskikh Institutov i
Laboratoriy Akademii Nauk SSSR. Za 1941 - 1943. (Information
requested.)

[This book is a compilation of several hundred abstracts of articles
previously published in Soviet scientific periodicals, monographs,
etc. Seven abstracts selected from the book are presented herein.]

SOVIET RESEARCH ON FLAME PROPAGATION AND DETONATION PHENOMENAExperimental Proof of the New Theory of Flame Propagation and Determination of
the Heat of Activation and of the Reaction Speed in a Flame

P. Ya. Sadovnikov,
G. A. Barskiy,
Ya. B. Zel'dovich

A basic conclusion of the new theory is the statement that in a flame the chemical reaction proceeds at a temperature close to the maximum temperature of combustion (that is, at 1,500 - 3,000 degrees for most mixtures), even in a mixture poor in fuel and O_2 and rich in reaction products on account of diffusion exchange of a layer in which the reaction of combustion products proceeds by strata, disposed side by side. The speed of chemical reaction under these conditions and the thermal conductance of the reacting layer determine the velocity of flame propagation. Such a theory differs substantially from the old viewpoint in which the velocity of flame propagation depended upon the speed of heating of the mixture to the temperature of ignition, around 400 - 800 degrees.

A series of experiments were carried out in which the velocity of flame in mixtures of CO with air were compared for various temperatures, to which mixtures various amounts of combustion products were admixed. It was shown that the velocity of flame in a heated mixture containing combustion products is equal to the velocity of flame in a cold undiluted mixture, if the temperatures of combustion and the composition of the combustion products of both mixtures are the same. These experiments directly confirmed the basic conclusion of the new theory. From our viewpoint the change of the initial temperature or the admixture of combustion products influences the velocity of propagation only indirectly, through the change of the temperature of combustion and of

- 1 -

CLASSIFICATION

CONFIDENTIAL

STATE	<input checked="" type="checkbox"/> NAVY	<input checked="" type="checkbox"/> NSRS	DISTRIBUTION																	
ARMY	<input checked="" type="checkbox"/> AIR	<input checked="" type="checkbox"/> FBI																		

CONFIDENTIAL

50X1-HUM

the temperature of the chemical reaction in the flame. By studying the influence of the admixture of combustion products on the velocity of flame, we obtain information about the dependence of the speed of chemical reaction on temperature at which the reaction proceeds, and it is possible to find the heat of activation of the reaction in the flame. By knowing the absolute value of the velocity of flame, the thermal constants of the mixture, and the heat of activation, we find also the absolute value of the rate of liberation of heat and the value of the speed of chemical reaction in the flame. Such experiments we conducted for various mixtures of CO by two methods:

1. By measurement of the velocity of flame propagation above and below in vertical pipes open above: for small velocities, by visual means according to stopwatch; for large velocities, by registering the passage of flames through a certain place of the pipe according to variations in the resistance of a tungsten wire included in the circuit of a "loop" device.

2. By bombs: for low pressures, in a spherical glass bomb; but for atmospheric and higher pressures, in a cylindrical steel bomb with a thick-walled glass window; for central ignition, the flame propagation was photographically registered in the initial section of the course (up to 30 percent of the bomb's radius). In this first phase, part of the burning mixture does not exceed 0.1-1 percent of the whole quantity, the change of pressure disregarded. We introduce certain results:

Composition				Temp. of Com-	Activation	Rate of Liberation of
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	bustion (°K)	Heat (cal/mol)	Heat (K cal cu m/hr)
67 CO,	33 O ₂	2 H ₂ O		3,000	75,000	140 x 10 ⁹
29 CO,	71 air,	2 H ₂ O		2,370	46,000	15 x 10 ⁹
50 CO,	50 air,	2 H ₂ O		2,030	20,000	5 x 10 ⁹

The data is of significant interest for thermotechnics, since ordinary values, at the present time, in combustion steam boilers, of the rate of liberation of heat are from 300,000 to 3,000,000 K cal cu m/hr.

This data was published in the Scientific-Technical Bulletin iKhF (1941) and was in the monograph of Ya. B. Zel'dovich, Theory of Combustion and Detonation of Gases. (Publishers of the Academy of Sciences, 1944).

The Velocity and Extent of Flame Propagation in Hydrogen-Bromine Mixtures

V. I. Kokocheskvili
Ya. B. Zel'dovich

The velocity of flame propagation in H₂ + Br₂ mixtures has been measured in relation to composition, pressure, and amount of the H Br admixture. Due to reliable knowledge concerning the velocity and the process of the H₂ + Br reaction and confirmed by spontaneous-combustion tests, the H₂ + Br₂ system permitted comparison of the experimental value of the velocity of flame propagation with that calculated by the new diffusion theory. The calculations consist of:

1. determination of the theoretical temperature T of combustion according to the heat of reaction and to the specific heat of the products, from calculation of the dissociation $2\text{H Br} \rightleftharpoons \text{H}_2 + \text{Br}_2$ and $2\text{H Br} \rightleftharpoons \text{H}_2 + 2\text{Br}$;

- 2 -

CONFIDENTIAL
CONFIDENTIAL

CONFIDENTIAL

50X1-HUM

2. calculation of the reaction speed according to known constants of the chain reaction $H + Br_2 \rightleftharpoons HBr + Br$, $Br + H_2 \rightleftharpoons HBr + H$ for conditions in the reaction zone adjoining the products which are heated to combustion temperature;

3. calculation of the velocity of propagation according to reaction speed and heat conductivity.

The agreement attained must be considered satisfactory. In this fashion, the calculation of the absolute value of flame velocity in the reaction process was first successfully carried out. During determination of the extent of propagation, it was noted that mixtures with an excess of bromine had the greatest extremes of limiting compositions for up and down flame propagation. In accordance with the work of Drozdov and Zel'dovich, this result is explained by the difference in the molecular weight of H_2 and Br_2 , which causes the difference in the intensity of diffusion and heat conductivity. This is also the reason for the unusually interesting new form of flame spread from above downwards, first observed in the work reported on.

In mixtures containing 60 percent Br_2 + 40 percent H_2 , the flat front is unstable and collapses in spite of the stabilizing influence of the gravitational field (ignition from above) into separate globes of flame, due to the dependence of velocity upon the curve obtained for diffusion which is more effective and intense than heat conductivity.

The Theory of Powder Combustion

Ya. B. Zel'dovich

The phases through which burning powder passes, the phases which determine the combustion rate, the relationship between the chemical kinetics of the reaction and the combustion rate, the ignition of powder, and the limits of steady-state combustion -- all of these problems are examined. Theories which assume that the surface powder molecules are activated by molecular impact of the reaction products on the gaseous phase (Letan, Yamagn, Kroy and Trimshaw) are shown to lead to absurd values of combustion rate and heat flow and are therefore incorrect. Consequently, the theoretical conclusion of the combustion law $u = \eta/p$ is incorrect. (Many authors have experimentally established that $u = u_0 p^v$, where $0.5 < v < 1$).

At the time of combustion the powder first warms up in the solid phase to the temperature at which it gasifies. The products of gasification heat up still further (in the gaseous phase) and they react with generation of heat and are transformed into the end products of combustion. The combustion rate is especially dependent on the rate of heat liberation in the chemical reaction, while the rate of the other process of initial warming and gasification are established automatically in accordance with the rate of chemical reaction. The latter assumption distinguishes our conception from that of Myuraur. The reaction takes place at a temperature close to that of combustion T_2 , and if the speed of the reaction is proportional to $p^n \cdot \exp(-E/RT)$, then the rate of the combustion is proportional to $p^{n/2} \cdot \exp(-E_3/RT_2)$. The dependence of the

powder combustion rate on the initial temperature and heat value of the powder is indirectly bound up with the dependence of the combustion temperature T_2 on these values.

- 3 -

CONFIDENTIAL

CONFIDENTIAL

50X1-HUM

This part of the presentation of burning powder resembles the picture given earlier by Belyayev (IKhF) of the combustion of vaporizing explosives; the quantitative treatment makes use of the theory of flame propagation in gases, given by Zel'dovich and Frank-Kamenskii.

In the process of combustion, the initial heating of hard powder from the low initial temperature to the final gasification temperature is accompanied by the penetration of a heat wave into the depth of the powder and by the creation of a specific supply of heat in the layer of heated powder. This supply is constant and does not enter into the calculations during steady-state combustion. However, the creation of such a reserve is a necessary condition for combustion. In this fashion, the basis is established for the theory of combustion, the calculation of heating time, and amount of heat necessary for combustion of powder and the condensed explosives.

A detailed analysis of the combustion process under a given condition of surface heating of a substance leads to the conclusion that steady-state combustion can take place only when the temperature of the material is not too low. Under opposite conditions extinguishment occurs which depends not on secondary causes, but on the rapid combustion of the heated layer with the ensuing diffusion of heat in the depth of the compressed explosive or powder.

The theory's next limit of the possibility of steady-state combustion was observed experimentally on the burning of liquid explosives (nitro-glycol, nitroglycerine) by Andreyev (MFTI) and Belyayev (IKhF). (This work was published in the Journal of Experimental Theoretical Physics, Vol XII, 1942.)

The Detonating Properties of Explosives

Yu. B. Khariton

Examination is made of the circumstances under which solid or liquid chemical compounds and mixtures become explosives. The problem is approached in the light of an earlier assertion that detonation can take place only when the ratio of time T (during which the high pressure located in the detonating wave front causes a dispersion of the material to time τ (during which the reaction is completed basically under the conditions created by the detonating wave) exceeds a certain fixed value (generally, speaking, greater than unity).

The magnitude of τ is related to the physicochemical properties of the system only when T depends on the geometrical characteristics and may then be regarded as proportional to the minimum dimension of the charge, for example, the diameter of a cylindrical charge. Therefore, by increasing the diameter of the charge it is always theoretically possible to achieve such values of T that the ratio $\frac{T}{\tau}$ will be large enough to secure detonation. All factors, therefore, favoring increase in T and decrease in τ facilitate detonation. The value of τ is determined by the physicochemical properties of the material. The value of T , along with the physicochemical properties, is determined by the charge size and the nature of the sheath covering and, as is evident from considerations of "similarity" (dimensional analysis), T is proportional to the minimum charge size (for example, the diameter of a cylindrical charge) and approximately linearly related to the square root of the ratio of sheath mass to charge mass, if the sheath shatters through the action of the explosion.

- 4 -

CONFIDENTIAL

CONFIDENTIAL

50X1-HUM

In the case of a sheath that does not shatter, l becomes infinitely large and the detonation propagates until such small values of charge diameter at which heat transfer from the reaction zone into the walls begins to have substantial values. A substance or mixture that is usually explosion proof under ordinary circumstances can be detonated by the use of a sufficiently large charge or by fitting the charge into a shatterproof sheath.

The principle which states the value of the ratio $\frac{T}{\tau}$ necessary for detonation makes it possible to estimate the duration of reaction on the detonation wave front and, consequently, to study the dependence of reaction duration on the most diverse factors. Data on reaction duration obtained in this manner permit in a number of cases the drawing of essential conclusions on the process of reaction in detonation waves. In the light of this principle, examination is made of that amount of minimum initiating charge which will set off the detonation of any explosive material.

Similarities in Detonation Phenomena (Dimensional Analysis)

Yu. B. Khariton
Ya. B. Zel'dovich

It is universally accepted that, in explosive charges of different sizes, the explosion processes are "similar" in all respects. Actually this is not so, as is evident from the extinguishment of detonation when the diameters of cylindrical charges are small enough. Yu. B. Khariton expressed the opinion that extinguishment takes place when the scattering of the charge due to the high pressure which exists in the detonation front takes place in a shorter time than the time τ of the course of reaction of decomposition of an explosive substance.

Since for all mechanical phenomena the time scale in explosions is proportional to the dimension R of the charge, it may be assumed that on the boundary between extinguishment and diffusion of detonation a certain criterion $\frac{R}{a\tau}$ assumes

a completely definite value (here R is a characteristic dimension of the charge; a is a certain fundamental velocity, for example, the speed of sound in explosion products or in a mixture of the parent material and explosion products.)

In the work reported on, application is made of the criterion $\frac{R}{a\tau}$ for studying the character of the phenomena of incomplete detonation. It is assumed that for complete detonation pressure may be expressed as a function of: the relative distance $\frac{l}{R}$ (l is a distance counted off from a certain point of the charge),

the criterion $\frac{R}{a\tau}$ and the characteristic pressure, for example, the pressure of detonation P_{det} ; thus: $P = P_{det} \cdot f\left(\frac{l}{R}, \frac{R}{a\tau}\right)$.

Accordingly, the impulse of the shock wave will be expressed by $i = R P_{det} \varphi\left(\frac{l}{R}, \frac{R}{a\tau}\right)$.

For various types of explosive materials and mixtures the form of functions f and φ may somewhat differ, but these differences will not be significant. The value of τ depends on the physicochemical properties of the system. Especially interesting from the viewpoint of the application of the theory of similarity (dimensional analysis) is the case of mixtures when $\tau = \tau(\delta)$ where δ is a dimension characterizing the dispersion of the mixture. If τ is proportional to δ , then "self-modeling" of the phenomena of incomplete detonation takes place; that is, complete similarity of the explosion process holds true for simultaneous "similar" variations in dispersion and charge sizes. In general,

- 5 -

CONFIDENTIAL

CONFIDENTIAL

50X1-HUM

the search for "similar" processes for charges in various sizes and with varying degrees of dispersion makes it possible to draw essential conclusions concerning the reaction mechanism. Then the criterion R has large

values, approximation to complete detonation takes place and, correspondingly, complete similarity of explosion phenomena holds true for changes in charge dimensions.

The Theory of Detonation Distribution, The State of Detonation Products For Various Conditions

Ya. B. Zel'dovich

This work (ZhETF, 12, 389, 1942) examines the distribution of pressure, density and velocity of detonation products in the following two cases:

1. The case of the detonation of a spherical charge set off by an initiator located in the center of the charge. In this instance, the maximum pressure and momentum attainable in the wave front fall off very rapidly in the layers located behind the front; in other words, after achieving maximum density at the moment that chemical reaction ends, the detonation products then undergo rapid expansion and reduced pressure results (one third to one fourth) while the detonation wave moves on and encompasses new layers of explosive material (the conclusions are equally applicable to detonation of gaseous mixtures and solid or liquid explosive materials). The limiting rules pertaining to pressure distribution are determined for general conditions and a complete calculation is made of the distribution when the products possess large thermal capacity.

2. The case of unidimensional detonation, for example, the distribution of detonation in a long pipe, where the distribution processes are studied for various velocities. In particular, detailed examination and theoretical confirmation are made of the detonation fuse method employed in blast technique in which the velocity of propagation throughout the charge is determined by the fuse properties and exceeds the thermodynamic velocity which depends on the properties of the charge (patent of the US firm "Hercules Powder"). In this case, the maximum achievable pressures are lower than those for detonation with thermodynamic velocity; however, the duration of action increases considerably. The increase in duration creates more favorable conditions for utilizing the chemical energy of low-grade explosive materials.

Calculation of Detonation Velocity and Condition of Explosion Products in the Detonation Wave Propagated in Condensed Systems

Ya. B. Zel'dovich
S. B. Ratner

The velocity of detonation D is determined by the ratio between the pressure and the density of explosion products. In solid and liquid materials, the velocity is 2-4 times greater than the velocity (D_{ig}) calculated under the assumption that the laws of ideal gases apply to explosion products. In 1912, Taftanel' and Detrich [Detrich?] first expressed the velocity of detonation by adopting, for the products of detonation, the equation $p \cdot (v - a) = f$, usually applied in internal ballistics (a = co-volume, f = RT the force of detonation products),

$$D = 6.41 \sqrt{\frac{p_0}{1 - a p_0}}$$

where p_0 is the original density of the explosive material. Schmidt (1936) made use of this expression reduced to the form

- 6 -

CONFIDENTIAL

CONFIDENTIAL

50X1-HUM

$$D = D_{id} \cdot \frac{\rho_0}{1 - \alpha \rho_0},$$

and he calculated α according to experimental data on $D = f(\rho_0)$ taken for powdered TNT, TEN, and other explosive materials with varying degrees of compression. Calculations demonstrated that α is not constant and that it decreases with an increase in density. Since the formulae of the hydrodynamic theory of detonation introduces not only the pressure for a given density (in equations of conservation), but also the derivative of pressure (in the conditions stated by Zhug - Kryussar, relating to the velocity of sound in the products), Schmidt's result implies that the formulae of Taffanel' and Dotrish and of Schmidt, studied under the assumption of a constant α , are actually not applicable to the detonation of explosive materials.

From the general properties of Giugonio's adiabatic curve, it may be shown that with a given measured velocity of detonation Schmidt's calculation give decreased values of pressure, density and velocity of the products of detonation in the detonation wave front.

In general, by assuming $\rho = f[v - d(v)]$ and solving the equations of hydrodynamic theory without other assumptions or approximations, we obtained for the detonation velocity and for a specific volume of detonation products ($v = 1/\rho$)

$$D = D_{id} \left[\frac{v(K_1 + 1) - v \frac{d\alpha}{dv}}{(K_1 + 1)(v - \alpha)} \right] \sqrt{\frac{K_1}{K_1 - \frac{d\alpha}{dv}}},$$

$$v_0 = v + \frac{v - \alpha}{K_1 - \frac{d\alpha}{dv}},$$

where $K_1 = \frac{c^2 + R}{c^2}$ is the maximum value of the exponent of Poisson's adiabatic curve for a low density. Calculation of D_{id} does not present difficulties (see the work by Z & R in collected Reviews for 1940).

If the function of $\alpha(v)$ is known, then for v_0 given, we find v with the aid of the 2nd equation, and by substituting the first, we get the value of $D(v_0)$. On the other hand, if we consider that $D(v_0)$ is determined by experiment, we can regard this system of equations as an expression for the calculation of $\alpha(v)$. In general, its solution is difficult since D is known as a function of P_0 (or of $v_0 = \frac{1}{\rho_0}$), when α depends on v . At the present time, we are seeking to solve the problem by calculating the repulsive force between molecules in a continuation of the work of Landau and Stanyukovich.

- E N D -

- 7 -

CONFIDENTIAL